

# ASTER, A MULTINATIONAL EARTH OBSERVING CONCEPT

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## ABSTRACT

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a facility instrument selected for launch in 1998 on the first in a series of spacecraft for NASA's Earth Observing System (EOS). The ASTER instrument is being sponsored and built in Japan. It is a three telescope, high spatial resolution (15 to 90 meters on the ground depending on the telescope) imaging instrument with 15 spectral bands covering the visible through to the thermal infrared. It will play a significant role within EOS providing geological, biological, and hydrological information necessary for intense study of the Earth.

The operational capabilities for ASTER, including the necessary interfaces and operational collaborations between the U.S. and Japanese participants, are under development. EOS operations are the responsibility of the EOS Project at NASA's Goddard Space Flight Center (GSFC). Although the primary EOS control center is at GSFC, the ASTER control facility will be in Japan.

The planning and scheduling of ASTER operations will be a complex exercise, not only because of the international interfaces but also because the instrument can be programmed to function in a variety of configurations, and because the limited downlink bandwidth dictates that the instrument be used in a selective manner to observe specified targets, not in a continuous survey mode. The long term average data rate for this instrument is approximately 8% of its peak capabilities.

Central to ASTER's long term operations will be a global mapping program, which will readily consume the instrument's background observation time. The more foreground operations, i.e. those with less long term

planning or for limited target areas, fall into several categories. The majority of these are routine monitoring operations, each requiring between 1 and 1,000 ASTER scenes. The greatest degree of planning will be for single sites with coordinated ground or aircraft observations. Some investigators require one-time observations of a site or region of the highest possible quality, necessitating repeated observations. Cloud studies can utilize data acquired in a less-structured/random manner. There are also the usual targets of opportunity.

These various observing requirements necessitate a variety of mission operations and data downlinking capabilities. The most complex will involve planning, acquisition, and analysis of data at a rate allowing immediate decisions on subsequent data acquisitions by this or associated instruments/spacecraft. Some data will be downlinked directly to regional receiving stations rather than via the standard EOS routing. The decision-making process required in these operations will entail close collaboration between U.S. and Japanese teams.

ASTER's scientific utilization is the responsibility of a joint U.S.-Japanese Science Team. There is a Team Leader and a number of Team Members making up the U.S. component of the Science Team in a similar manner to other EOS facility instruments. The authors are associated with the U.S. Team Leader in the development of mission operations and ground data systems on behalf of the U.S. Team.

## 1. INTRODUCTION

EOS, as part of NASA's Mission to Planet Earth, aims to advance the scientific understanding of the Earth by monitoring the various components of the Earth system on a global scale. This includes the acquisition of a 15-year baseline of remote-sensing measurements and the

development of a large data and information system to provide access to this baseline for scientists studying Earth systems, particularly those focusing on global change. The ASTER Project supports these goals by producing scientifically-useful products that quantify various aspects of the earth system, and by providing access to these products via EOSDIS.

The ASTER Project has its beginnings in both Japan and the U.S. In Japan, the Ministry of International Trade and Industry (MITI), organized government funding of the Intermediate Thermal Infrared Radiometer (ITIR) instrument project for remote sensing data to assist in mineral exploration throughout the world. ITIR was to have five channels in the 8-12  $\mu\text{m}$ . In the U.S. a proposal was submitted to NASA to build the Thermal Infrared Ground Emission Radiometer (TIGER) to make quantitative measurements of emitted radiation from the Earth's surface in the 8-13  $\mu\text{m}$  and 3-5  $\mu\text{m}$  atmospheric windows, at spatial and spectral resolutions appropriate for geological, climatological, hydrological and agricultural studies. NASA headquarters decided on a single instrument built by the Japanese based on the ITIR but with an improved capability to meet the needs of the U.S. TIGER team and the EOS community. Negotiations led to the addition of the Japanese ASTER instrument to the U.S. EOS project and the merging of the Japanese and U.S. science teams.

The ASTER instrument will be flown on the EOS AM1 platform, the first of three polar-orbiting EOS platforms. The Japan Resources Observation Systems Organization (JAROS) is responsible for the design and development of ASTER which is subcontracted by JAROS to NEC, MELCO, Fujitsu and Hitachi. Although the primary EOS control center is at GSFC, the ASTER Instrument Control Center (ICC) will be located in Japan. The ICC will be responsible for final operations decisions and preparation of the instrument commands. Goddard performs the uplink. The international Memorandum Of Understanding and Project Implementation Plans between the U.S. NASA and the MITI of Japan are still in preparation.

The ASTER instrument is comprised of three optical telescopes (radiometers): (1) a visible-near infrared 2-telescope system (VNIR) that is capable of providing stereo data for the production of digital elevation models, (2) a short wave infrared telescope (SWIR), and (3) a thermal infrared telescope (TIR). All three

radiometers can be operated independently and all three are individually pointable. The instrument features high spatial and radiometric (thermal) resolution. The nadir-viewing swath width is 60 km. With its pointing capability, ASTER is capable of viewing any point on Earth every 16 days. Because of its polar orbit, it can view any point above 45 degrees every 7-9 days and any point above 69 degrees, every 3-4 days. It takes 48 days to provide full surface coverage.

The goals for the ASTER instrument are to obtain high-resolution, targeted data in the visible and infrared; a global land map using all three radiometers and stereo data using the nadir and back-viewing telescopes of the VNIR. Such information will be used in studies of surface radiation balance, evaporation and evapotranspiration, vegetation, soils, the hydrogeologic cycle, surface-atmosphere interactions, volcanic processes, sea ice and cloud studies and to produce an earth surface digital elevation model.

Since ASTER is the only high-spatial resolution imager planned for EOS AM1 it will be relied upon to provide surface temperatures, surface emitted and reflected radiances, and digital elevation models at a finer spatial scale than other EOS instruments.

The investigators who will utilize ASTER data include the U.S. and Japanese ASTER Science Teams, the EOS Interdisciplinary Scientists, other EOS scientists, government agencies, and members of the international science community at large. The data is also required by other EOS AM1 instruments for calibration and validation of their data. Researchers will be able to request that specific data be acquired for their studies. Raw and processed data products will be available from a data processing and archiving center.

Considerable planning will be required in order to achieve the ASTER science objectives with the Japanese-provided instrument on a U.S. platform for a joint U.S.-Japanese Science Team. Several meetings have been held by the EOS Project, EOS AM1 Project, and the joint Science Teams to insure complete communication.

## 2. CAPABILITIES AND CONSTRAINTS

The sun-synchronous 705-km orbit of the EOS AM1 platform that will carry ASTER is characterized by a descending 10:30 am

equator crossing, a 98.5-deg inclination, and a 100-minute period. The duration of one cycle (the length of time from one orbit until the nadir track repeats) is 16 days.

EOS AM1 will carry four instruments in addition to ASTER. They are the Clouds and Earth's Radiant System (CERES), the Multi-Angle Imaging Spectro-Radiometer (MISR), the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the Measurement of Pollution in the Troposphere (MOPITT).

The VNIR acquires data in the wavelengths 0.52  $\mu\text{m}$  to 0.86  $\mu\text{m}$  in three bands. All three view through the nadir telescope and one band, the 0.76 to 0.86  $\mu\text{m}$  band, views through the back looking telescope. The SWIR covers the 1.60 to 2.43  $\mu\text{m}$  wavelengths in six bands. The TIR covers the 8.3 to 11.3  $\mu\text{m}$  in 5 bands. The spatial resolution of the VNIR, SWIR, and TIR are 15, 30 and 90 meters on the ground, respectively. The radiometric resolution is <0.5%, <0.5% to 1.3% and <3K for the three telescopes.

Thermal dissipation, power use and data volume all limit the number and extent of observations. The VNIR and SWIR telescope systems will be capable of up to an average duty cycle of 8%, e.g. they can be operated continuously for up to 16 minutes in one orbit; however, to do so will require that they be turned off in the immediately preceding and following orbits. The TIR will be capable of a 16% duty cycle. If, instead of operating continuously, the radiometers are turned on and off more than once in an orbit, the achievable duty cycle is significantly reduced due to the large operating overhead associated with each observation. Each radiometer has different preparation and calibration cycles that are periodically required. The instrument data rates are 62 Mbps for the VNIR, and 23 and 4.1 Mbps for the SWIR and TIR respectively. The two orbit average data rate allowance is 8.3 Mbps.

The cross-track swath-width is 60 km at nadir. The telescopes are capable of slewing independently providing cross-track coverage of up to 232 km. At this time, it appears that lifetime limitations of the slewing hardware will limit the VNIR and SWIR to 10,000 pointing changes each over the 5 year lifetime of the mission. The science request is for 15,000 to 20,000 pointings. The TIR pointing limitation is 200,000, but this number is required to include repointings for thermal and pointing calibrations before and after each observation. The distance

between successive groundtracks at the equator is 172 km.

Most observations require maximum cloudfree viewing. Observations may be acquired many times before a cloud-free view of a particular area is obtained. The ASTER Science Project is currently studying the probability of acquiring the full land surface cloud-free in the 5 year mission. The results may indicate a requirement to use both long-term and short-term cloud predictions in planning.

### 3. PLANNING AND OPERATIONS DEVELOPMENT

Science requested observations will fall into several categories: routine monitoring; single sites with coordinated observations; one-time, high-resolution, cloud-free images; and cloud studies. The majority of observations are routine monitoring operations, each requiring between 1 and 1,000 ASTER scenes. The greatest degree of planning will be required for single sites with coordinated observations from the ground, from aircraft or from other EOS AM1 instruments to obtain spatial and DEM observations and for calibration and atmospheric correction. Some investigators require one-time observations of a site or region of the highest possible quality, that may necessitate repeated observations to acquire. Cloud studies can utilize data acquired in a less-structured/random manner.

The Science Team has proposed a basic operating plan for ASTER which allocates 5% of its viewing time for emergency observations (natural disasters, etc. and other ephemeral targets that might include power plant accidents, etc.), 20% for Science Team-requested targets for specific research topics, 50% for Regional multi-temporal Monitoring (regional change), and 25% for Global Mapping, e.g. to observe the entire land surface, cloud-free, at least once during the 5-year mission.

Whatever final scheduling plan is adopted, the planning and scheduling of ASTER operations will be a complex exercise, not only because of the international interfaces and the breadth of the science data expected, but also because the instrument can be programmed to function in a variety of configurations, and because the operations constraints will dictate to a large degree the instrument use. The challenge will be distributed between the U.S. and Japan.

The steps by which science data is translated from the wishes of an investigator to data that is specifically useful to his or her investigation, can be divided into uplink and downlink elements.

### 3.1 Uplink

The uplink elements of the instrument operations begin with the request by an investigator or a Science Team for data acquisition and are completed when the implementing command sequence is transmitted to the instrument from the spacecraft computer.

Operations planning for the uplinking of requests will begin with the design of the data acquisition request (DAR). DARs will have to contain sufficient information to allow them to be evaluated for their scientific merit and appropriateness for the mission and for technical feasibility and, most importantly, to allow them to be ranked for the purpose of scheduling among all the DARs submitted to the system.

The plan for managing data acquisition requests by investigators is not finalized. A preliminary scenario is that any investigator who wants to specify targets and data acquisition parameters will prepare a data acquisition request (DAR) and submit it to the EOS Information Management System (IMS) for preliminary evaluation. (Fig. 1) This will include screening for conflicts with known operational constraints and a search to determine whether the data already exists in the archive. The DAR would be forwarded to the ICC for reformatting into detailed observation schedules and commands. A subset of the ICC and the joint Science Team, using criteria developed with the Project Scientist, will evaluate and prioritize the requests and resolve any conflicts that arise. The set of ranking criteria may include the number of requesters for the same data, the priority of the science, the permanence and changing nature of the target, target size, telescope required, repointing requirements, day or night observation, conflicts, etc. The ICC will be responsible for the final instrument schedule, instrument commanding and the health and safety of the ASTER instrument.

A conflict-free prioritized activities list will be sent to the EOS Operations Center (EOC) at GSFC for creation of a composite schedule and uplink to the spacecraft. Command sequences are stored in the spacecraft memory before being sent to the ASTER instrument.

DARs may be long term, i.e. submitted well before launch of the 5-year mission; short term, submitted 7-21 days prior to the requested observation; or 'targets of opportunity' (TOOs), that may be requested only hours before the target orbits. TOOs may be requests for data on important ephemeral processes, natural or otherwise, including volcanoes and forest fires. Short term requests will be evaluated at the ICC to determine their priority relative to the long term planned observations. If a short term request or a TOO is inserted into the queue, other observations will be bumped and initiate a 'domino process' to re-select all the previously scheduled acquisitions according to their priorities and within the constraints of the instrument and spacecraft. There will be an estimated 350 observations per week.

The ICC and the IMS receive from the EOC the platform composite activity schedule. Members of the science community can access the IMS to obtain status updates for their own requested observations.

Central to ASTER's long term operations will be the global mapping program that has the objective of mapping the entire surface of the planet with all three telescopes. In order to achieve this objective, global mapping data will be collected whenever the telescopes are turned on, but not acquiring specific investigator requested data. At a 40-50% observation rate for global mapping, and assuming 10% cloud-free observations, it could take 4 years to acquire a high percentage of the global map. This might be reduced by strategic planning of the mapping of the requested targets.

The hierarchy of priorities (from the draft MOU between NASA and MITI concerning the flight of ASTER on EOS AM1) that determine the final activity schedule at the ICC and the EOC in descending order are:

1. platform health, instrument health and safety, and data to assist in declared national or international environmental emergency;
2. calibration/validation including special observations to enable cross calibration of instruments, calibration of individual instruments, and support of specific validation measurements;
3. large data acquisitions either to continue long-term data records or acquisitions of time-critical data on specific earth phenomena ;
4. support of large-scale multi-investigator field experiments;

5. smaller data acquisitions including specific requests by International Partners or NASA.

### 3.2 Downlink

The downlink procedure begins with the transmission of the data from the spacecraft recorder via TDRSS, to White Sands, N. M. (although in some cases it might be direct down-linked to Japan). (Fig. 2) Then it is shipped via EOS Communication System (ECOM) to the EOS Data Operations System (EDOS) in West Virginia where the level 0 data are constructed. In the current baseline plan the level 0 data are then shipped to Japan where level 1 processing is carried out. The Project is evaluating the option of a parallel level 1 processing capability in the U. S. A copy of the level 1 data is shipped from Japan to the Land Processes Data Active Archive Center (DAAC) at the EROS Data Center (EDC) in South Dakota where the data is archived and where it will be processed applying investigator developed algorithms to produce the data products required by each investigator.

The joint U.S.-Japanese Science Team has the responsibility of guiding the development of ASTER data systems including include defining and specifying data products, developing the algorithms and production software to produce the data products from the ASTER data and related data sources, validation and quality assurance of the data products, and finally, software maintenance and upgrading.

The preparation of standard and special data products lists is in process at this time. EOS system constraints have pared down the original list of ASTER data products requested by the Science Team to 6. Algorithms to convert the ASTER observations and related data to useful science products will be developed by members of the Science Team with support from ASTER Science Project algorithm developers. The Project Software development team will translate the algorithms into EOS system compatible production software for final science product preparation by the ASTER Distributed Active Archive Data Center (DAAC).

Requests for data products may be part of a DAR when an investigator initiates a request for new data, or may be made directly to the DAAC for existing data.

### 3.3 Tools

Tools including a data acquisition simulation tool, a planning and visualization tool, and an evaluation and prioritization decision tool will all be required to provide support to the uplink and downlink development.

With support from the EOS Instrument Operations Support Task, a data acquisition simulation tool is under development that has the capability of generating representative single-cycle targetted and global mapping observations, the '16-Day Scenario'. Scenarios generated by the simulation tool will be useful for long-term mission design and in supporting operations development by bringing out the problems that will be encountered in the operations development process.

To generate the scenario, the data acquisition simulation tool selects, within mission and instrument constraints, as many as possible of the targets requested by the investigators that it will be able to acquire in the next 16 days. In the current version of the scenario, science targets are given priority over the global mapping objective.

When the latest iteration of the 16-Day Scenario was run, operated wherever possible responding to an actual ASTER operating environment, 42% of the 1100 designated targets were acquired, 15% of the global land surface was covered with global map observations (all 3 radiometers), and 19% of the land was observed in stereo. In this iteration, science targets were not prioritized, cloud cover was not considered for the global mapping and TOOs were not included. These constraints and other s not yet considered will certainly impact the results of operating the simulation tool. They will be included in future versions of the simulation tool.

A visualization and planning tool derived from this simulator and a current EOS multi-instrument prototyping activity will be designed and prototyped. The objectives for the visualization tool include a digital global map that will illustrate the accumulation of data over time as a function of acquisition plan, the ability to scan through time and to zoom, the ability to add specific targeting and TOOs as "what ifs", and the ability to separate the data from the three telescopes.

Finally, an operations concept under discussion at this time is the creation of a U.S. Instrument

Support Terminal (IST) to be used for cooperative operations activities with the Japanese ICC for designing, developing and implementing an automatic DAR prioritizing process that would yield a conflict-free prioritized list of targets to the ICC.

#### 4. CONCLUSIONS

The system and science operations planning and development processes require close collaboration between the U.S. and Japanese teams. There has already been a very successful meeting of the minds for everyone's benefit at the Working Group meetings and Joint Science Team meetings where surprises in the form of operating constraints were worked together to find best possible solutions. This spirit of cooperation that has successfully addressed duty cycle, for example, promises to smooth the interfaces.

This is a very exciting Project not only from the perspective of the science contributions, but from the diversity of the groups working the operations issues and the challenge of making it all come together.

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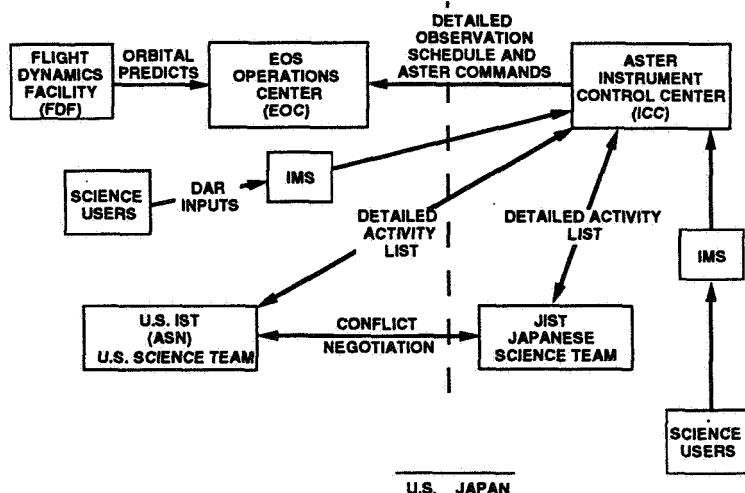


Figure 1. Flight Operations Segment (EOS)

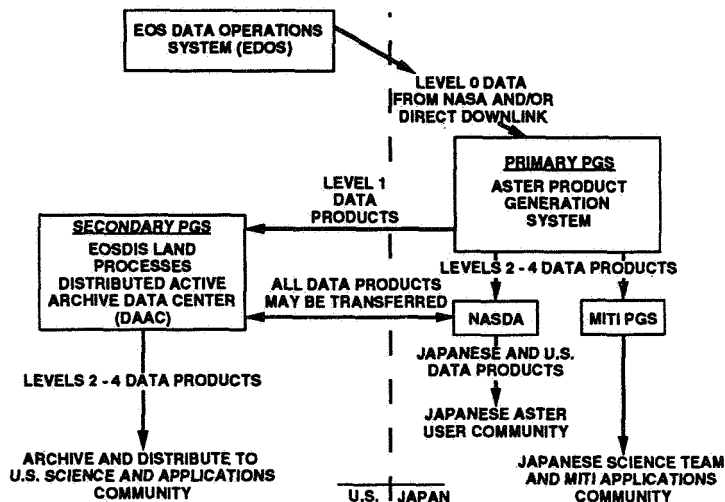


Figure 2. Science Data Processing Segment (DPS)